Observing Guidance for Tropical Cyclones

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Introduction: Tropical cyclones (TCs), including hurricanes in the Atlantic and typhoons in the Western Pacific, are of great military and civilian interest around the world. In order to improve the prediction of TC intensity, structure, and track, THe Observing-system Research and Predictability EXperiment (THORPEX) Pacific Asian Regional Campaign (T-PARC)/Office of Naval Research (ONR) Tropical Cyclone Structure-08 (TCS-08) field campaign was conducted during August and September 2008. The international campaign, with nine participating nations, aimed to observe TCs and their environment throughout their lifecycle. To accomplish this, four aircraft stationed in Guam, Japan, and Taiwan flew a total of 76 missions (including 21 missions by the NRL P-3), during which 1149 vertical soundings of atmospheric data were taken via instruments dropped from the aircraft. In addition, 223 soundings were taken from instruments dropped from high-altitude balloons drifting westward from their launch site in Hawaii. These atmospheric observations were subsequently ingested into operational weather prediction systems to improve real-time TC forecasts. For the first time ever, the number of these special observations taken in the Western Pacific was similar to the number of special observations taken to improve hurricane forecasts in the Atlantic (Fig. 9).

To support the field campaign, NRL produced real-time products based on global-scale and storm-scale forecast models and their adjoint systems. Adjoints allow for the calculation of the sensitivity of TC forecasts to changes in the initial state in a mathematically rigorous, computationally feasible manner. These products provided information on features and processes that influence the TC track and intensity forecasts, and were instrumental in determining resource allocations and deployments (such as when and where aircraft would take additional observations). NRL uniquely contributed both global and storm-scale products, providing critical information on both large-scale remote influences and the sensitivity of the forecast to fine-scale structures within the storm itself.

Global-scale Products: NRL used the Navy Operational Global Atmospheric Prediction System (NOGAPS) forecast and adjoint models[1] to produce targeted observation guidance twice daily for five fixed regions, plus additional products during high-interest periods, at 150 km resolution. These guidance products provided information on where the 48-h TC forecasts would be most sensitive to errors in the atmospheric analyses, and therefore would be "targets" for additional observations to improve the quality of the analysis in these regions. The target guidance was produced with a 48-h to 60-h "lead time" to allow for flight track planning and deployment. These products were useful both for aircraft deployment purposes and for understanding the physical processes that control tropical cyclone motion. For example, in Fig. 10, the NOGAPS forecast sensitivity (shaded) for TC Jangmi on 00 UTC 28 September 2008, indicates that the 48-h forecast of TC Jangmi (22N, 122E) is sensitive to changes in the peripheral anticyclonic (clockwise) flow to the southeast of the storm center, as well as a weakness in the anticyclonic flow to the north of the storm center (as denoted by the 500-hPa streamlines). The importance of both these features for influencing TC motion has been previously suggested through simple dynamical studies as well as complex numerical integrations.

Storm-scale Products: Storm-scale targeted observing products were produced using the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS®) forecast and adjoint system twice daily, centered on storms of interest, at 40-km resolution. These products were produced with 24-, 36-, and 48-h lead times. A unique aspect of this nonhydrostatic adjoint system is that an exact adjoint to the explicit microphysics has been developed[2] and used during T-PARC/TCS-08. An adaptive response function region was used to target favorable areas for TC genesis and development. Results indicate that forecasts of TC formation in the Western Pacific are very sensitive to the initial state. The adjoint-based sensitivity fields indicate structured patterns in the wind, thermal, and microphysical fields that project on to the model-simulated deep convection, which ultimately influences the intensification rate. For example, sensitivity fields for typhoon Sinlaku valid at 1200 UTC 10 September 2008 are shown in Fig. 11. The sensitivity of the final time kinetic energy in the box shown in the figure to the initial vorticity at 2 km indicates a highly structured pattern with anticylonically curved sensitivity maxima (Fig. 11(a)). The region of the perturbation total energy (Fig. 11(b)) maximum is well sampled by the C-130 aircraft soundings deployed during this flight. In general, relatively small adjoint-based basic state perturbations on the order of observational errors (1 m s^{-1}, 1 K) lead to rapid growth rates in the near-surface horizontal velocity of more than 10 m s^{-1} and a 6 hPa deepening rate of the central pressure over 24 h.

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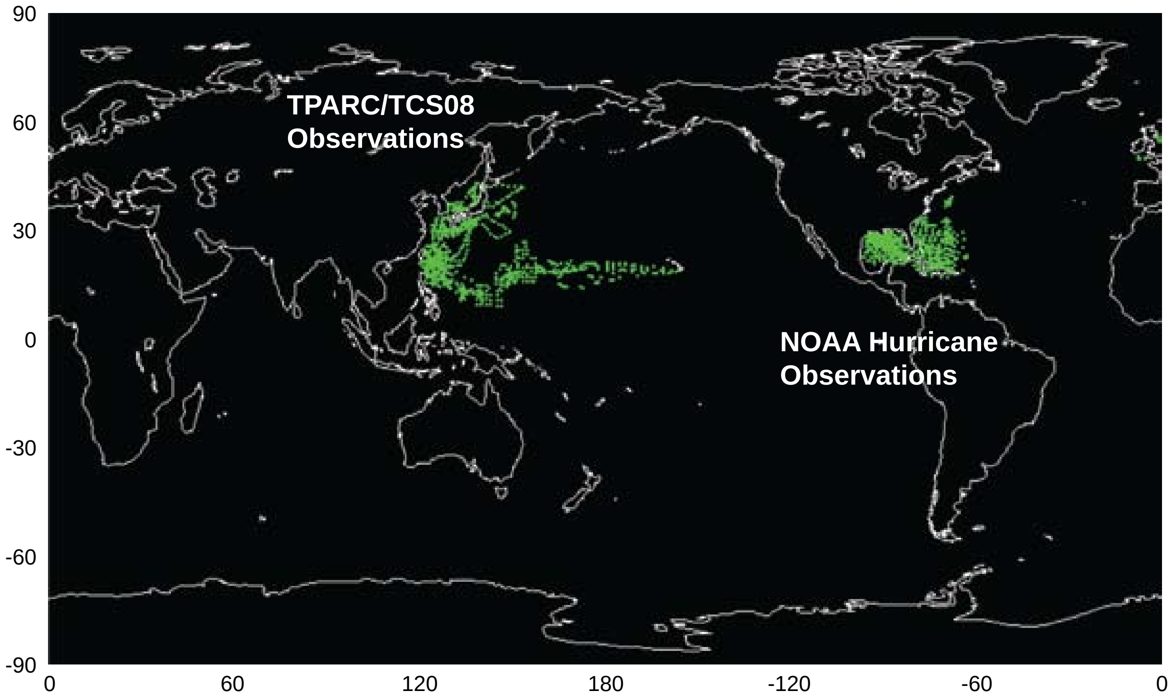

FIGURE 9
Locations (green dots) of the special atmospheric soundings taken from aircraft and high-altitude balloons during September 2008. Figure produced by Fleet Numerical Meteorology and Oceanography Center.

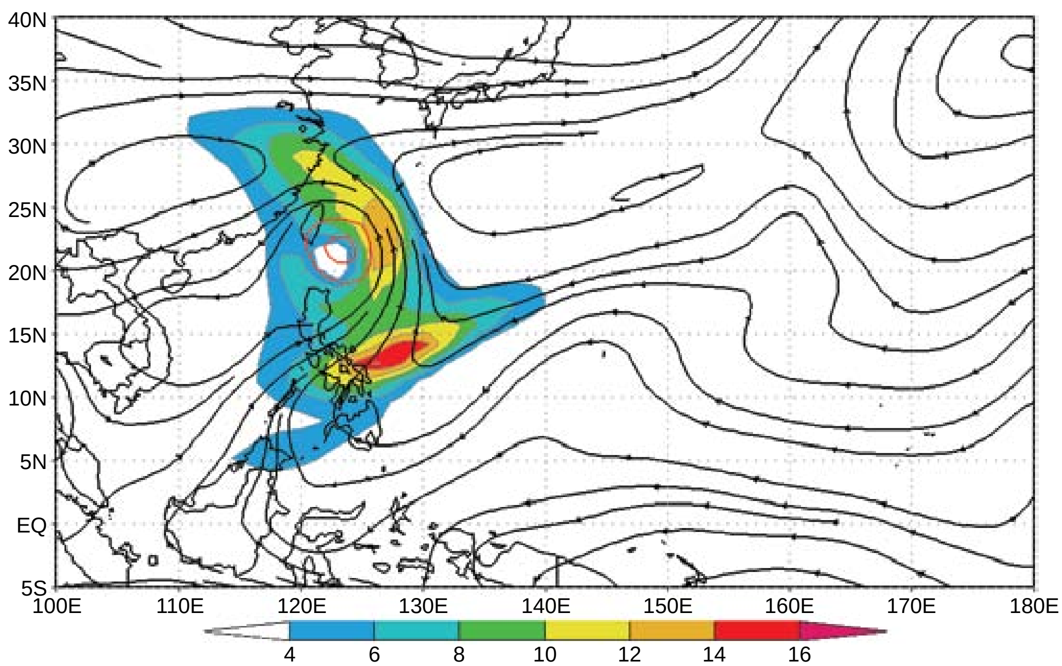

FIGURE 10
Vertically integrated sensitivity of the NOGAPS 48-h forecast of TC Jangmi, valid at 00 UTC 28 September 2008, shaded, J kg^{-1}, along with streamlines for the 500-hPa wind (black), and contours of 850-hPa vorticity at 10 and 20 x 10^{-5} s^{-1} (red). Jangmi is centered at 22N, 122E.

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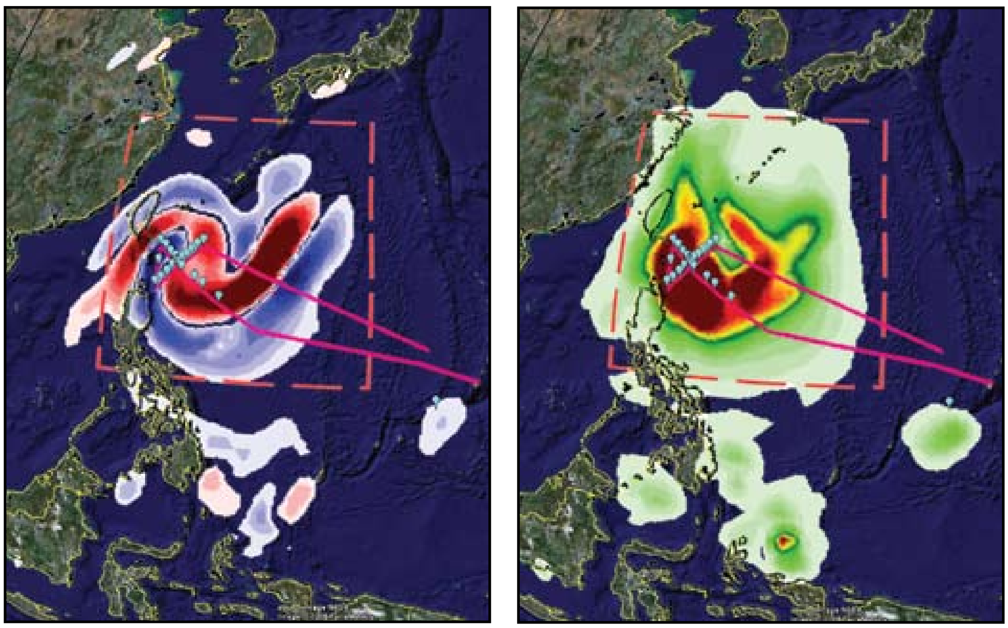
[Sponsored by ONR]

References

[1] C.A. Reynolds, M.S. Peng, S.J. Majumdar, S.D. Aberson, C.H. Bishop, and R. Buizza, "Interpretation of Adaptive Observing Guidance for Atlantic Tropical Cyclones," *Mon. Wea. Rev.* **135**, 4006–4029 (2007).

[2] C. Amerault, X. Zou, and J. Doyle, "Tests of an Adjoint Mesoscale Model with Explicit Moist Physics on the Cloud Scale," *Mon. Wea. Rev.* **136**, 2120–2132 (2008).



(a) (b)

FIGURE 11

The COAMPS® adjoint sensitivity fields for the (a) vorticity ($m^2\ s^{-1}$) and (b) vertically integrated total energy ($J\ kg^{-1}$) valid at 1200 UTC 10 September 2008 for typhoon Sinlaku. The C-130 aircraft flight track is shown by the solid magenta line, and the red dashed box indicates the region over which the response function is applied. The aircraft sounding deployment locations are represented by the turquoise balloon symbols.